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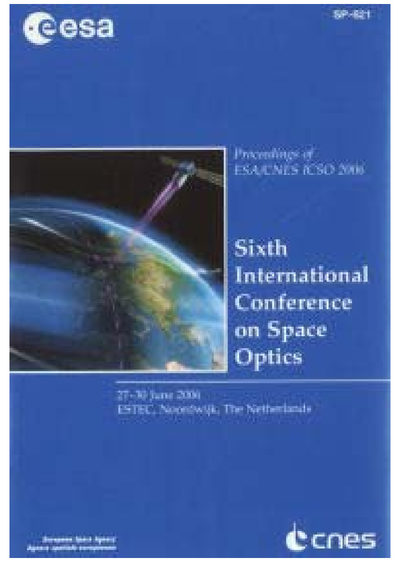

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OPTICS FOR THE CANADIAN HYPERSPECTRAL MISSION (HERO)

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ABSTRACT

The proposed Canadian Hyperspectral Environment and Resources Observer (HERO) mission is described.

Preliminary, phase A, instrument design forms are discussed.

1. MISSION OBJECTIVE

The HERO mission objective is to deliver high quality hyperspectral data for the Canadian and international users, covering wide range of applications such as: geological mapping of the Canadian north, improved species and bio-health assessment as part of a national forest inventory, environmental mapping, monitoring of carbon sources and sinks on land, assessment of productivity in coastal and littoral aquatic ecosystems. From a technological point of view, it is also expected that the mission will stimulate the development of new and better algorithms for the exploitation of data , and will advance space imaging spectrometry in general, as well as Canadian expertise and capabilities in that area.

2. HERO INSTRUMENT REQUIREMENTS

The main HERO instrument requirements are summarized below.

Table 1.

Parameter	**Value**
Imager type	pushbroom
Altitude	~700 km
Swath width	≥30 km
Ground sampling distance (GSD)	30 m
Spectral coverage	400-1000nm VNIR 1000 – 2500 nm SWIR
Spectral sampling interval (SSI)	7.5 nm
Spectral resolution (FWHM)	~10 nm (full width at half maximum)
Smile distortion	<0.1 SSI
Keystone distortion	<0.1 GSD
Total MTF	>0.3 @ Nyquist
Signal to noise ratio (SNR) for typical signal (30% albedo, 30 deg SZA)	600:1 @ 650nm 400:1 @1650 nm 200:1 @2100 nm

From the point of view of the optical design, the most challenging parameters listed in Table 1 are: the SNR values requiring a fast system (F/2.2, aperture ~320 mm) and the very low keystone and smile distortions. Both distortions are characteristic for the pushbroom spectrometers and must be kept at small fractions of Ground Sampling Distance (GSD) and Spectral Sampling Interval (SSI), respectively. Reduction of keystone errors is especially important because it causes spectra combination from adjacent spatial locations; correction of these errors cannot be accomplished without an a priori knowledge of the form of the spectra to be recovered. Errors due to smile, on the other hand, are more easily corrected in the retrieval process and can be characterized in orbit, using for example the atmospheric features as described by Neville et al [1].

2. OTHER PUSHBROOM INSTRUMENTS

In Table 2 the main design characteristics of all pushbroom type instruments currently in space are listed and compared to HERO. It shows broad acceptance of the Offner scheme of design. One exception is MERIS, which employs the Dyson type optics. The table reveals also that the HERO design requirements are the most demanding of the critical optical design parameters - F/#, aperture size and distortions - particularly because they have to be met simultaneously. For example, MERIS has lower F/# but much smaller aperture and thus smaller aberrations; CHRIS has small distortions, but high F/# and smaller aperture.

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Table 2.

Instrument Spacecraft/ Target Launch date Optics Type Disperser	F/#	Aper-Ture (mm)	SNR max	Smile (SSI)	Key-Stone (GSD)
VIMS-V Cassini/Saturn 1997 Offner Grating [3]	3.2	45	?	<1	?
HYPERION EO-1/Earth 2000 Offner Grating [4]	12	125	160	0.3 -Vnir 0.1 -Swir	0.18 -Vnir 0.25 - Swir
CHRIS Proba/Earth 2001 Offner Prisms [5]	6	120	200	0.05	0.06
MERIS Envisat 2002 Dyson Grating [6]	1.9	32x20	?	0.08	0.1 ?
OMEGA (Vnir) Mars Express 2003 Rowland Grating	3.7	15.6	>100	?	?
VIRTIS-M Rosetta/Comet 2004 Offner Grating [7]	5.6-Vnir 3.2-Swir	47.5	>100	?	?
CRISM Mars Reconn-aissance Orbiter 2005 Offner Grating [8]	4.4	100	550	1.3	~0.9
HERO ?	**2.2**	**320**	**600**	**<0.**	**<0.1**

3. HERO PHASE A DESIGN CONCEPTS

The Offner/Dyson designs require a spherical grating with the groove angle constant along grating surface, which is considered essential for the spectrometer performance. Gratings of that type, despite being successfully produced and employed in space, pose still a manufacturing challenge [2]. For that reason, an all reflective flat grating design was attempted, resulting in a design meeting all the requirements. However, necessity for the curved toroidal slits and complex aspheric mirror surfaces is a serious drawback of that scheme.

An Offner scheme (two spherical mirrors and a convex spherical grating) was also investigated with good results obtained for F/2.2 without any decentration of the surfaces. The main disadvantages are very little clearance around the grating, preventing effective baffling, relatively big size of the spectrometer (approx. 0.5 x 0.5 x 0.3 m) and big grating (dia.~120 mm).

In an effort to find an alternative solution, the Dyson type design (a thick double pass plano-covex lens and a concave grating) was investigated.

The arrangement in Fig.1 shows the most complicated example as it is composed of two pairs of the VNIR (7-8) and SWIR (5 – 6) Dyson block spectrometers. Each pair covers 35 km of swath by two, 17.5km long, left and right overlapping subsections. Necessity to split the swath resulted from the baseline selection of the 640 pixels long TCM 6604 series Si/MCT detectors from the Rockwell Science Centre. Light from a TMA telescope is divided between VNIR and SWIR subsystems by the Pick-off Mirror (9) and then focused on the slits, which are directly deposited on the entrance surfaces of the Dyson blocks.

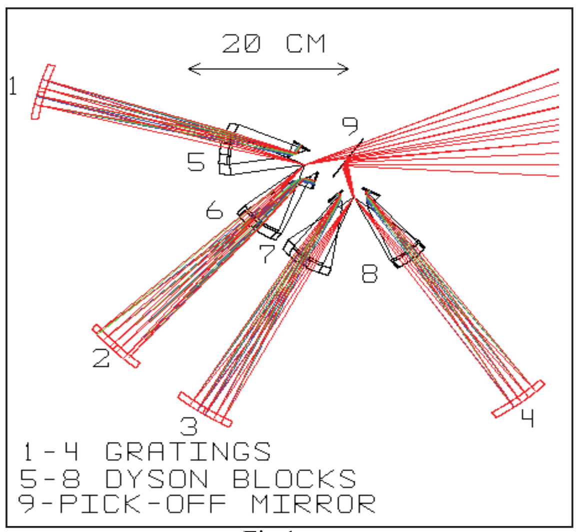

Fig.1

A TIR surface placed after each slit directs the beam towards exit convex surface of the block and then to the concave grating. After dispersion, light travels back and is reflected towards the detectors by the second TIR surface formed in the Dyson blocks. The final distance to the detectors is about 1-2mm. The largest separation between the slits corresponds to 4 GSD, equivalent to ~17.4 ms delay in the acquisition time between the spectrometers. The F/# of the system is 1.7. The minimum MTF values at Nyquist are 0.78 and for VNIR and 0.82 for SWIR. The keystone and smile distortions are below 0.1 of the GSD and ISS, respectively.

Obviously, the layout as in Fig.1 can be significantly simplified (two spectrometers instead of four) if the 1000 pixels long detectors were employed. Yet other potential simplification comes from the MCT detector cut-on wavelength lowered from ~1 micron to ~0.4 micron, allowing to use a single spectrometer covering the whole VNIR-SWIR spectral range. Detectors of that type are currently under development, for example, at Rockwell Science Centre and Sofradir.

One of the potential simplifications of the Dyson scheme is shown in Fig.2 in which slits (one transmissive and one reflective) are positioned at a convenient distance from the Dyson blocks.

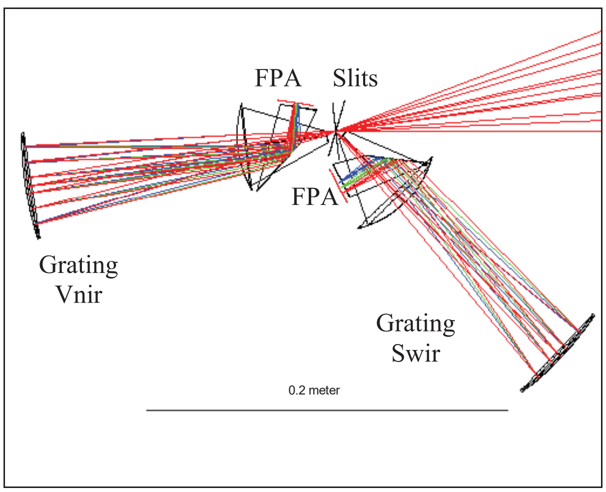

Fig.2.

The design offers greater manufacturing simplicity of the lens-slit subsystem and may be especially valuable for the preliminary testing of the spectrometers.

The main characteristics of the above design are listed in Table 3.

Table 3.

Optical component or parameter	Characteristics or Value	Comment
Fore-optics type	TMA	All aspherical
Aperture (mm)	320	
Spectrometer type	Dyson	All spherical
Spectrometer magnification	1	
Image space F/#	2.18	
Grating aperture (mm)	46	
Grating type	Spherical concave	
Grating frequency (grooves/mm)	31.2	
Slit type	Straight, transmissive or reflective	
Smile across whole spectrum	~0.033 SSI	SSI=7.5nm ⇔ 1pixel
Keystone across whole spectrum	~0.033 GSD	GSD=30m ⇔ 1pixel
Spots maximum geometrical radius (μ m)	10	
Minimum MTF	0.76	At Nyquist
Matching detector	1000 x 280 x 30 μ m	One spectrometer configuration
	1000 x 80 x 30 μ m-VNIR	Two spectrometers configuration
	1000 x 200 x 30 μ m-SWIR	

4. REFERENCES

[1] R. A. Neville, L. Sun and K. Staenz, "Detection of spectral line curvature in imaging spectrometer data", Proceedings of SPIE: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery IX , S.S. Shen, P.E . Lewis, Editors, Vol. 5093, 144-154, SPIE Bellingham, 2003.
[2]P.Mouroulis, D.W.Wilson, P.D.Maker, and R.E.Muller, "Convex Grating Types for Concentric Imaging Spectrometers", Applied Optics, Vol.37, No.31, November 1, 1998.
[3] F. Reininger, M. Dami, R. Paolinetti, S. Pieri and S. Falugiani, "Visible infrared mapping spectrometer - visible channel (VIMS-V)", SPIE Vol. 2198, 239-250, 1994.
[4] J. Pearlman, S. Carman, C. Segal, P. Jarecke, P. Barry, "Overview of the Hyperion Imaging Spectrometer for the NASA EO-1 Mission" IEEE 2001 International Geoscience and Remote Sens*ing* Symposium, July 9-13, 2001.
[5] M.J. Barnsley, J.J. Settle, M.Cutter, D.Lobb and F.Teston, 2004. The PROBA/CHRIS mission: a low-cost smallsat for hyperspectral, multi-angle, observations of the Earth surface and atmosphere, IEEE Transactions on Geoscience and Remote Sensing, **42**, 1512-1520, 2004.
[6] D.Loiseaux, A.Michel and C.Babolat, "MERIS Camera Development: Particular Processes for an Original Concept", SPIE Vol.2209, 252-261, 1994.
[7] F. Reininger et. al., "VIRTIS: Visible Infrared Thermal Imaging Spectrometer for the Rosetta Mission", SPIE Vol. 2819, 66-77, 1996.
[8] S. Murchie et. al., "CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) on MRO (Mars Reconnaissance Orbiter)", Instruments, Science, and Methods for Geospace and Planetary Remote Sensing, SPIE Vol.5660, 66-77, 2004.